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Demoz Gebre-Egziabher, Associate Professor

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Department of Aerospace Engineering and Mechanics | University of Minnesota
107 Akerman Hall | 110 Union St, SE
Minneapolis, MN 55455

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AFOSR/RSE
875 North Randolph Street, Suit 325 | Room 3112
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14. ABSTRACT

The objective of the work described was to build a nanosat as part for the UNP-6 competition cycle to demonstrate the use of the Global Positioning System (GPS) as passive bistatic radar for on-orbit relative navigation, proximity detection and remote sensing. This was the University of Minnesota's entry into the UNP-6. This bistatic radar will use GPS signals reflected or re-radiated from objects on orbit to detect, localize and perhaps characterize or "image" them. At a minimum, reflected GPS signals can be used to provide a relative navigation measurement between spacecraft (range and velocity), allowing for a passive sensor with little additional mass and no extra power. This is particularly useful when navigating relative to non-cooperative targets (e.g, during operation for servicing malfunctioning satellites) where traditional carrier phase differential GPS techniques which rely on GPS measurement data exchange between vehicles cannot be used.

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EXECUTIVE SUMMARY

This report summarizes all the work done under AFOSR Grant FA9550-09-1-0210 at the University of Minnesota, Twin Cities Campus from April 2007 to December 2009. The objective of the work described was to build a nanosat as part for the UNP-6 competition cycle to demonstrate the use of the Global Positioning System (GPS) as passive bistatic radar for on-orbit relative navigation, proximity detection and remote sensing. This was the University of Minnesota's entry into the UNP-6. This bistatic radar will use GPS signals reflected or re-radiated from objects on orbit to detect, localize and perhaps characterize or "image" them. At a minimum, reflected GPS signals can be used to provide a relative navigation measurement between spacecraft (range and velocity), allowing for a passive sensor with little additional mass and no extra power. This is particularly useful when navigating relative to *non-cooperative* targets (e.g, during operation for servicing malfunctioning satellites) where traditional carrier phase differential GPS techniques which rely on GPS measurement data exchange between vehicles cannot be used. The higher power and chipping rates available on the signals accessible to Department of Defense authorized users (i.e., the P(Y) and future M-code) may open up additional capabilities such as detection and characterization of close by targets on orbit. Finally, the bistatic radar can be an enabler for military and civilian remote sensing application where Earth reflected GPS signals allow characterizing the surface below that reflected the signal.

The University of Minnesota's proposed experiment for the University Nanosat competition was aimed at exploring this untapped capability of the GPS. The proposed experiment will demonstrate the performance achieved when using GPS in this manner for on orbit relative navigation. The space segment of the proposed experiment was to be carried out by a satellite (referred to as the "primary" satellite) which will deploy a target. The primary satellite was to be a redesign of the TwinSat (University of Minnesota's entry into Nanosat-5 competition). The redesign will incorporate a target which will be released once the satellite is on orbit. The primary satellite, equipped with GPS software receivers, was to collect specular reflections of the GPS signals from the dummy target. The target will be equipped with a simple GPS data logger (not a receiver) which will be used to estimate its position relative to the primary satellite in post-process. The data from the target will be relayed to the main satellite via a vehicle-to-vehicle data-link. The main satellite will broadcast all the data (from the main and target) to the ground station for post processing and validation.

The satellites to be built were to be named TwinSat. As the project proceeded, however, it was determined that the mission was to complex and posed too many risks for it to be completed successfully. Thus, the project was scoped down and reduced to a single satellite experiment. In this instance, the mission was going to be one where the satellite observed reflected GPS signals from the Earth below and attempted to characterize the nature of the reflecting surface. Hardware and software developed as part of this scoped down mission was presented at the Flight Competition Review (FCR) in Albuquerque, NM in January 2011.

EDUCATION MISSION ACCOMPLISHEMENTS

The TwinSat team consisted of students and faculty from a range of engineering disciplines. Currently, the group consists of 20+ graduate and undergraduate students. Since the emphasis of the project was on student education, students were involved in every aspect of the project, from

top level management through design, fabrication, and testing. As discussed below, the experience that students gained while participating in this project helped them in further academic and professional endeavors. For the graduate students involved in the project, TwinSat has given them an opportunity to pursue research for their dissertations. TwinSat is the third complete satellite design performed at the University of Minnesota.

Group Composition

As noted above, the TwinSat team consisted of both undergraduate and graduate students. The undergraduate students were from various science and engineering disciplines. As such, the program provided students with an excellent training in what it is like to work in an interdisciplinary engineering group. The size of the group of students that participated varied depending on what time of the academic year it was. However, during the regular academic year the group consisted of as many as 20+ students.

Educational Accomplishments

Aspects of the design of the TwinSat project was used as topics for independent study, Undergraduate Research Opportunity Program (UROP) and capstone design class projects. In this regard, the project was an effective vehicle in fostering and developing the skills in undergraduate students which enable them to conduct engineering research. Many of the members of the TwinSat team have now graduated and moved on to industry, civil service or graduate studies. With respect to the latter, two of the members of the team are current graduate students in the Aerospace Engineering and Mechanics program at the University of Minnesota. One is a Ph.D candidate at the University of Maryland. Another is a Ph.D. candidate in Aerospace Engineering at Gerogia Tech. A number of the students that are still here are the University of Minnesota as undergraduates will be starting the graduate careers at schools all round the county next fall.

BUDGET AND EXPENDITURE

The TwinSat project was completed using the funding supplied by the USAF and other in-kind support from local industry. In addition, some students were supported (in the form of undergraduate Research Assistants) using funding from NASA's space grant program via the Minnesota Space Grant.

SUMMARY

TwinSat was the nano-satellite that was designed by the University of Minnesota as part of UNP-6. The mission of TwinSat was to validate and demonstrate the use of the Global Positioning System (GPS) as passive bistatic radar for remote sensing and potentially on-orbit proximity detection. On January 17, 2011 a complete satellite was presented at the Flight Competition Review (FCR) in Albuquerque, NM. Even though TwinSat did not win the UNP-6 competition, it was a successful program in training undergraduate and graduate students in the art and science of satellite design.